Damara geology, from geosyncline to plate tectonics

A talk given by Nick Watson

to the West Midlands Regional Group of the Geological Society of London

9th April 2019
Talk Contents

- Introduction
- Namibia, research projects, and geology
- The conundrums
- Geology at two sites
  - Structure and stratigraphy
  - Ophiolites, volcanics, mélange deposits, suture zone
  - Batholiths
Damara reference documents

Publications on Geodynamic origin of Damara


Selected individual publications


Published geological maps (1:250,000 scale, Geological Survey of Namibia)

- Sheet 2214 ‘Walvis Bay’, 1995
- Sheet 2114 ‘Omaruru’, 1997
- Sheet 2216 ‘Windhoek’, provisional, 1998
Geology of Namibia
Geosynclinal theory

Site 1
Central zone
Structure and stratigraphy
Batholiths

Site 2
Southern zone
Ophiolites, mélange deposits, the suture zone, volcanics
Section through the Damara according to geosynclinal theory
Geodynamic models (up to 1983)

<table>
<thead>
<tr>
<th>MODEL</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PRE PLATE TECTONICS</strong></td>
<td></td>
</tr>
<tr>
<td>Geosyncline</td>
<td>Large linear sedimentary basin founded on continental crust, regarded as a weak crustal zone bounded by stable cratons</td>
</tr>
<tr>
<td><strong>PLATE TECTONICS – FAILED ARM OF A TRIPLE JUNCTION</strong></td>
<td></td>
</tr>
<tr>
<td>Aulacogen/modified aulacogen</td>
<td>Intracratonic fold belt, mantle plume leads to rift tectonics and diapirism, folding linked to gravitational instability in the lower lithosphere</td>
</tr>
<tr>
<td><strong>PLATE TECTONICS – WILSON CYCLE</strong></td>
<td></td>
</tr>
<tr>
<td>Plate tectonics – wide / narrow ocean</td>
<td>Wilson cycle of sea floor spreading, generation of oceanic crust, followed by creation of a forearc / passive margin basin with MORB volcanics, subduction and continental collision</td>
</tr>
</tbody>
</table>

Possible sinistral movement, transform faults and transpression applicable to all plate tectonic models?
Conundrums
Road Testing Plate Tectonics

• Continuous stratigraphy traceable over the whole orogenic belt, with continental crust in basement exposures
• The lack of a suture line between the two continents, marked by ophiolites and mélange deposits, and separating zones with different pre-collision sedimentation and deformation history
• Paucity of volcanics in the forearc trench deposits
• There is large volume of granite, but where are the tonalites (andesite volcanics source magma)?
Inverted bedding in Nosib quartzite at the Rooiberg
Etusis quartzite

Cross bedded arkosic quartzite

Rossing marble

Dolomitic fosterite marble with skarn lenses
Kuiseb schist folding and schistosity development

Structure

• Isoclinal $f_2$ fold core with cordierite porphyroblasts
• Sinous $S_1$ inclusion trails
• Coarse $S_2$ axial planar cleavage
Metamorphism in the Kuiseb schist

- Biotite + sillimanite + quartz $\Rightarrow$ cordierite + K-spar + H$_2$O + garnet
- Local partial melting
- $T = 650^\circ$C, $P = 4.25$ kbar, $X_{H_2O} = 0.125$ (425 MPa = c15 km cover)

---

1Barnes and Sawyer, 1980
Complex interference fold patterns in the Karibib marbles
Central zone structure and stratigraphy

- Line of section
- Multiple dome and basin features defined by Karibib marble
- Omaruru Lineament separates tectonic domains
- Single large dome defined by Karibib marble

Aerial view
Horizontal sections based on different interpretations
Horizontal compressive or vertical stress regime
Structure and stratigraphy

• Different theories for the origin of dome and basin structures
• Geosynclinal and intracratonic theories are supported by vertical tectonic interpretations – diapirs and high heat flow
• Horizontal movement – shear zones and interference folding – favours continental collision and plate tectonics
  (are the interference folds the higher crustal expression of shear zones at depth?)

• But reversal of vertical movement needed to explain graben to horst transition
Section through the Damara according to intracratonic aulacogen theory

Site 1

Okahandja lineament

Site 2
Southern margin – ophiolites, volcanics and mélange deposits
Data collation
Field mapping, sampling

Analysis
Mineralogy and petrography, XRF

Classification
T-tests, principal component analysis, cluster analysis, multiple discriminant analysis, variance

Mineral reactions
- Harzburgite + H₂O = hobnail serpentinite + magnetite
- Hobnail serpentinite + quartz = talc schist + H₂O
- Spinel harzburgite + H₂O = chlorite schist
- Lherzolite + H₂O = CPX bearing serpentinite = amphibole fels

Origin of serpentinites
- Originally depleted mantle rock
- Low grade metamorphism at spreading stage
- Cold emplacement with thrust tectonics
- Higher temperatures cause further dehydration reactions

Process of interpretation

1. Origin of serpentinites
   - Originally depleted mantle rock
   - Low grade metamorphism at spreading stage
   - Cold emplacement with thrust tectonics
   - Higher temperatures cause further dehydration reactions

1. Barnes, 1980
Matchless amphibolite – MORB geochemistry

Schist sequence – turbidites – associated with Matchless amphibolite

Pale hyaloclastic layers in between possible pillow lavas in fine grained amphibolite
Southern zone – an interpretation

Spreading

Subduction

Collision
Intense shearing in Kuiseb schist

Disrupted quartz veins and fold closures in strong transposition cleavage

Metamorphism

- Fe-garnet+Mg-biotite = Mg-garnet+Fe-biotite
- Almandine+muscovite = annite+2kyanite+quartz
- $T^\circ = 575^\circ$C and $P=6.3$ kbar (630MPa or c22km cover)

1Barnes, 1980
Thrust contact between Auas quartzite on the mountain range and underlying Pre-Damara basement in foreground

Large scale Type 3 refolded fold closure marks the NE limit of a major quartzite horizon in the lower part of the Damara
Ophiolites, volcanics, mélange deposits, suture zone

- Evidence is strong for oceanic crust but no typical ophiolites or mélange deposits
- Intracratonic theories cannot easily explain serpentinites
- MORB volcanics – the Matchless amphibolite, further evidence for oceanic crust
- Evidence for collision tectonics – shearing, sheath folds and thrusts
- Cryptic suture zone
Section through the Damara according to wide ocean plate tectonic model
Typical Damara granites fall in ‘granite/granodiorite’ field of QAP ternary diagram.

S-type granites (Salem, red granite)

I-type granites (Donkerhoek)

Mineralogy and geochemistry of Damara granites

1Miller, 1983
Batholiths

- Lack of tonalites (plutonic equivalent of andesite volcanics)
- Crustal signature for Salem suite
- Mantle signature for Donkerhoek granite
‘The intriguing implication is that the 2.0Ga rocks of the upper Damara basement are underlain by significantly younger continental crust.’
Hawksworth and Marlow, 1983
Central zone granites

Early granites folded around dome structure

Late granite intrusion in Kuiseb schist

Omaruru Lineament
Early

Leucogranite

Granodiorite – tonalite

Late
Summary

- 1970s research programmes – outcomes published in 1983
  - Plate tectonics supersedes geosynclinal theory
  - Different geodynamic models – fixism (vertical) and mobilism (horizontal)
- Law of superposition and the interpretation of structures
- The present is the key to the past – but should we worry if it’s not exactly the same?
- The Wilson Cycle – a useful framework for analysis and interpretation of a complex problem
- Some casual observations
  - Centre zone back arc developed separately from Southern zone forearc / passive margin sediments
  - Sheath folds at depth are separated from interference folds by Rossing marble décollement
  - Additional collision movement accounts for lack of tonalites, youthful isotope signature of granite intrusions, juxtaposition of back arc and forearc, early and late granites